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QUALITY OF STEEL MADE WITH IRON BLOWN
WITH BLAST HAVING A CONSTANT MOISTURE CONTENT.

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The introduction of constant-moisture-content blast in practice was held back for a long time on account of the possible danger of increasing hydrogen content in iron and in the finished steel. Only in 1950, the investigations conducted in a number of plants, the Kuznetsk Works (1) being in the first place, showed the baselessness of these apprehensions when applied to the making of plain carbon steels.

The present investigation had for its object the checking of the possibility of using constant-moisture blast in special steel plants, in particular at the Chebyabinsk Works.

In the course of this study, No. 1 and No. 3 blast furnaces of this plant, having working volume of 930 and 1380 cubic meters, were shifted on the constant moisture blast. Since the natural humidity of air in summertime reaches in the Chebyabinsk district 11-13 grams/M^3, the moisture content of the blast had to be held at 15 gr/M^3 in order to keep it constant.

No. 3 furnace was shifted on blast with this humidity (15 gr/M^3) on March 16, 1955; from April 13 to May 27 the moisture content was maintained at 20 gr/M^3.

No.1 furnace was switched on the constant-moisture blast on April 16, 1955; until May 20 it operated using blast carrying 15 gr/M^3 and from May 21 to June 7, 1955 with blast having 20 gr/M^3 of water.

A further increase of the humidity content to 25 gr/M^3 was abandoned in No. 3 furnace on account of the uneven operation of it; at that point the atmospheric humidity varied between 12 and 25 gr/M^3.

As a result of shifting blast furnaces on constant moisture blast (15-20 gr/M^3), their operation became more uniform; it became possible to raise the blast temperature from 450-550°C. to 750-800°, to hold blast temperature more constant, and to control furnace temperature by varying the humidity of the blast.

Production of No.1 furnace increased by 3% and that of No.3 furnace by 1.3%, the coke consumption was lowered by 6.5 and 1.3%, respectively.

Throughout the whole experimental period, the iron produced remained within permissible compositional limits, having a slightly high silicon and manganese content explainable by hot working and increased humidification of the blast.

A. Hydrogen content of iron and steel.

Experimental heats were made in 100 and 185-ton open hearth furnaces using scrap-ore process with a 60-65% hot iron charge and fired with a mixture of coke-oven and blast furnace gases. The No. 1 open hearth shop has here a 1300-ton mixer, and No.2 shop a 600-ton mixer.

The steel was bottom cast in 6.2-ton ingots. Altogether 97 experimental heats were made embracing four groups of steel: carbon steels (0.40-0.50% C.), high carbon (0.9% C.), chromium steel (0.20-0.40% C.) and manganese steels (0.50-0.65%C.).

Samples of iron for determining the hydrogen content were taken when filling ladles from a mixer or, occasionally, on casting the furnaces. Samples were also taken from open hearth furnaces throughout the heat using split chill molds and water quenching. Samples were stored prior to their analysis in dry ice. Hydrogen content was determined by the vacuum-heating method (2).

As it is well known, an accurate determination of the hydrogen content in iron by the vacuum heating method without a subsequent gas analysis is debatable (3), particularly in connection with grey, nodulized, and malleable irons (4).

This can be explained by the evolution of a certain amount of CO and CO_2 formed as a result of the reaction of the sample with the quartz tube in vacuum, or on account of the presence in iron pores. The surface of the pores oxidizes during the preparation of a sample and the scale reacts with carbon during deposition.

On this account, hydrogen determination in a sample based on the volume of the evolved gases might produce high results.

This error is not high, however, in case of white iron, provided the samples are sound (5). Since the iron of the samples was white as a result of the sampling technique employed, the results obtained in the present investigation can characterize the relative hydrogen concentration in the iron sufficiently well.

The average hydrogen content of the iron of experimental heats made with different moisture content in the blast was:

Moisture in blast, gr./M^3	Atmospheric	15	20
Number of heats	18	44	35
H_2 content in iron, cm^3/100 gr.	2.5	3.4	3.3

The gas content of the iron increases somewhat when a blast with an increased moisture content is used, but no linear relation between hydrogen content of the iron and the extent of blast humidity can be seen. It must be noted that hydrogen content of iron drops appreciably (0.5 cm^3/100 gr) from the moment of casting the blast furnace until it is charged into an open hearth furnace.

However, the hydrogen content of the metal during melting in an open hearth is not defined exclusively by the gas concentration of the iron. An average gas content of the metal in open hearth furnaces at the melt down appeared to be practically independent from the quality of iron and the moisture content of the blast, Table 1 and Figure 1.

Table 1. Average hydrogen content of the metal, $cm^3/100$ gr.

Blast humidity	Steel	No.of heats	Hydrogen content At melt down	Hydrogen content On teeming
Atmospheric	Carbon	4	4.6	4.6
	High Carbon	1	-	4.8
	Chromium	4	4.5	6.7
	Manganese	11	4.5	6.3
15 gr/M^3	Carbon	13	4.9	5.4
	High Carbon	3	4.9	6.6
	Chromium	8	4.7	6.6
	Manganese	15	4.3	6.6
20 gr/M^3	Carbon	9	4.4	5.3
	High Carbon	2	4.1	4.9
	Chromium	10	4.5	6.5
	Manganese	14	4.5	6.3

The final hydrogen content on teeming is also independent from its content in the iron, Table 1, Figure 2. It may be thought that the hydrogen content of the metal during an open hearth heat and teeming is primarily determined by such technological factors as metal temperature, slag basicity, etc.

The tendency of steel towards flakes formation cannot be characterized by the absolute hydrogen concentration in molten steel. On this account, hydrogen content was additionally determined in blooms having a cross section of 250 mm. Samples were made using a hollow drill (6).

The data obtained, Table 2, show that hydrogen distribution is not uniform over the cross section of blooms, the element concentrating preferentially in the central zone. In the outer layers of the bloom hydrogen content varied from 0.9 to 4.5 $cm^3/100$ gr., which is below its concentration in the molten steel, while in the axial portion of the bloom it fluctuated between 3.2 and 9.2 $cm^3/100$ gr. which, occasionally, was higher than its content in the molten steel.

Таблица 2

HYDROGEN CONTENT IN IRON, STEEL, AND ROLLED STOCK (CM^3/100 GR.)

Moisture Content of the blast, gr/m3	Hydrogen in iron	Heat number	Type of steel	Hydrogen in steel during teeming	Hydrogen in blooms at a distance from the surface in mm						
					10	30	50	72	92	120	Average
Atmospheric	—	8901	.50 C Mn steel	5,5	2,9	4,3	4,5	4,5	5,7	6,2	4,6
	—	8902		6,4	3,1	5,5	3,6	4,0	4,6	6,0	4,4
	2,5	8904		6,2	3,3	5,5	7,3	6,4	7,3	7,2	6,2
	2,2	8903		5,0	2,0	3,6	4,5	4,0	5,2	5,7	4,2
	3,1	10212		6,5	4,5	3,6	4,4	4,0	4,6	5,5	4,4
15	—	10272	.50 C Mn	6,4	2,3	4,4	5,5	4,4	4,1	3,9	4,1
	2,8	10244	Axle steel	4,7	2,6	3,7	4,9	5,1	7,0	9,2	5,1
	2,7	10257	.40 C Cr	7,5	2,8	3,1	3,9	3,9	4,0	6,0	4,0
	—	8930	.60 C Mn	6,8	2,6	2,5	3,3	2,2	2,9	4,2	2,9
	3,9	8944	.50 C Mn	5,1	4,3	4,4	4,6	5,2	5,9	6,3	4,5
20	—	81002	.50 C Mn	5,9	0,9	1,2	1,5	1,6	1,9	2,9	1,7
	—	8980	.40 C Cr	6,5	1,5	2,6	3,5	3,4	3,1	5,0	3,3
	3,0	52040	.40 C Cr-Ni	6,4	2,1	1,8	2,6	2,9	2,6	4,5	2,7
	3,1	10322	.40 C Cr	6,6	1,3	2,7	2,3	1,8	2,8	4,0	2,5
	—	42033	.45 C Cr-Ni	7,4	2,6	—	2,4	2,4	2,0	3,2	2,5

However, the average hydrogen concentration in blooms was lower than in molten metal. No relation was found between the average hydrogen content of the blooms and the moisture content of the blast furnace blast.

Nonuniform distribution of hydrogen along the cross section of blooms is caused by its seggregation during solidifcation of the ingot and depends, therefore, on its weight and solidification conditions. The average hydrogen content is defined to a large extent by the hot working conditions and cooling of the finished stock.

Its concentration in the blooms is not defined, apparently, by its content in the iron. All attempts to find a direct connection between gas concentration of the liquid steel and the quality of the finished metal were, therefore, unsuccessful.

B. Quality of the finished metal.

Among the quality characteristics of the metal determined in the present investigation were flake sensitivity, mechanical properties and macrostructure.

The metal of the experimental heats was examined for flakes sensitivity in the shape of air cooled 245 x 245 and 300 x 300 mm blooms. As it has been shown by the data describing experimental heats, the absolute concentration of hydrogen in the liquid metal and in blooms doesn't characterize by itself flaking susceptibility of a steel of a given type.

In Table 3 are given the results of blooms examination in regard to flaking made on air cooled stock, the hydrogen content of which has been determined. There is no relation between flakes frequency and the gas content of solid metal.

Table 3. Comparison of flakes frequency and hydrogen content of blooms (Blown with atmospheric moisture content).

Heat No.	8901	8902	8903	8904	10212
Steel type			.50% C. manganese		
Section, mm			245 x 245		
Aging time, days	32	30	30	30	32
No. of flakes	6	3	13	3	8
Size of flakes, mm	3-5	2-7	4-8	3-4	2-3
Average H content, cm^3/100 gr	4.6	4.4	4.2	6.2	4.4

(Blown with 15 gr./m^3 of water blast)

Heat No.	10272	10244	10257	8930	8944
Heat type	.50% C_1 Mn	Axle	.40% C_1 Cr	.60 C_1 Mn	.50% C_1 Mn.
Section, mm	245x245	190x190		245 x 245	
Aging time, days	38	16	15	14	32
No. of flakes	18	10	63	6	25
Size of flakes, mm	2-20	2-4	3-15	3-10	3-15
Average H content, cm^3/100 gr.	4.1	5.1	4.0	2.9	4.5

The maximum hydrogen content was found in Heats 8904 and 10244, namely 6.2 and 5.1 cm^3/100 gr. but the number and size of flakes in these heats do not exceed corresponding indices for hydrogen content of 2.9 - 4.6 cm^3/100 gr. in blooms.

Chromium steel blooms cooled in air had the most flakes though this phenomenon is unconnected with an increased hydrogen content in these steels.

Manganese steels had about the same hydrogen content (5.6-6.3 cm^3/100 gr) as the chromium ones, but much higher (by 0.5 - 1.2 cm^3/100 gr.) than the carbon steels. At the same time, flakes susceptibility of manganese and carbon steels is actually the same. A much higher sensitivity of chromium steels must be, apparently, explained by much higher structural stresses occurring in chromium-bearing steels.

Any definite relation between steels affected by flakes and the quality of the iron used also could not be found. The largest number of flakes in blooms of carbon steel was recorded in the metal made with iron blown with air having atmospheric humidity and in chromium and in manganese steel with that blown with a higher moisture content. However, in the last case a number of heats was entirely free from flakes.

In the finished rolled stock made from all experimental heats, as well as from production heats for 1956, no scrap due to flakes was recorded. This indicated that the cooling practice adopted at the Chebyabinsk plant for billets and finished stock prevents flake formation in heats made of iron blown with atmospheric or constant moisture blast.

Since mechanical characteristics of steel depend on many factors, such as chemical composition, thermal treatment, gas content, degree of reduction, etc., while the number of experimental heats was comparatively small, a comparison of mechanical properties was made between the production metal made in 100-ton furnaces using iron blown either with atmospheric moisture blast or that carrying 15 gr./m^3 of water. Heats having about the same cross section of the finished stock were selected, and the same heat treatment applied to all test bars.

Table 4. Mechanical properties of finished steel.
(Blown with atmospheric air)

Type	Cross Section	No.of Heats	Tensile Strength K/mm^2	Yield Point K/mm^2	Elongation %	Reduction of area, %
45	50-90	16	70.0	42.7	18.2	40.8
30 x Г T	130	3	151.0	140.3	10.8	56.9
18 x Г T	120-150	7	146.0	134.0	11.8	53.6
20 x H3A	110-160	10	106.5	96.2	13.7	66.1
50 Г	120-140	13	75.8	45.6	18.4	42.1
Axle steel	190-200	8	62.0	35.5	21.5	41.2
			(Blown with 15 gr./m^3 of water)			
45	50-90	17	68.3	42.2	19.4	41.1
30 x Г T	110-130	11	162.0	153.0	13.5	53.3
18 x Г T	115-170	10	145.3	136.2	12.3	59.8
12 x H 3 A	110-150	10	106.4	96.7	14.7	66.8
50 Г	120-140	8	75.7	46.2	19.3	42.8
Axle steel	190-200	11	62.0	36.5	20.9	39.6

The data given in Table 4 show that mechanical properties do not depend on variations in the melting practice. Slight variations of individual properties are associated, apparently, not with the qualities of the iron, but with the fluctuations of the chemical composition of the finished metal.

In the study of macrostructure of the metal, the total and axial porosity, as well as the presence of blow holes, were examined in blooms rolled on the 780 mill.

For the evaluation of macrostructure were used the following data obtained on inspecting production steel made from irons blown with a different moisture content. Figures given as numerators are those for blast with the natural moisture content; figures used as denominators correspond to blast containing 15-20 gr./m^3 of moisture.

Type	Carbon	Manganese	Chrome-Nickel	18X ГT-30X T
No. of heats	$\frac{44}{1588}$	$\frac{13}{84}$	$\frac{18}{86}$	$\frac{10}{94}$
Porosity, %				
Total	$\frac{1.47}{1.19}$	$\frac{1.38}{1.44}$	$\frac{1.22}{0.865}$	$\frac{1.24}{1.07}$
Axial	$\frac{0.18}{0.21}$	$\frac{0.10}{0.316}$	$\frac{0.27}{0.107}$	$\frac{0.23}{0.167}$

No appreciable differences among all groups of steels tested have been found as a function of humidity of the blast furnace blast.

Conclusions.

1. In making steel in open hearth furnaces by the scrap-ore process, the hydrogen content of the iron has no effect on hydrogen content in the metal at the melt down and during teeming.

2. No direct relation between sensitivity to flaking and hydrogen content of the liquid iron was found. The cooling and heating practice adopted at the Chelybinsk plant for flake sensitive steels assures their absence in steel made by any variation of practice.

3. The macrostructure of blooms rolled on the 780 mill does not depend on the moisture content of the blast used for making iron.

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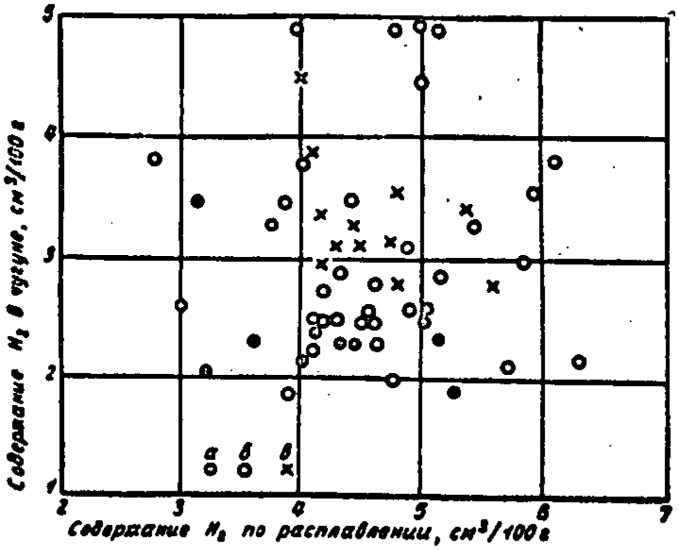

Рис. 1. Влияние содержания водорода в чугуне на содержание водорода в металле по расплавлении мартеновской ванны:
а — при доменном дутье естественной влажности; б — при дутье влажностью 15 г/м³; в — при дутье влажностью 20 г/м³

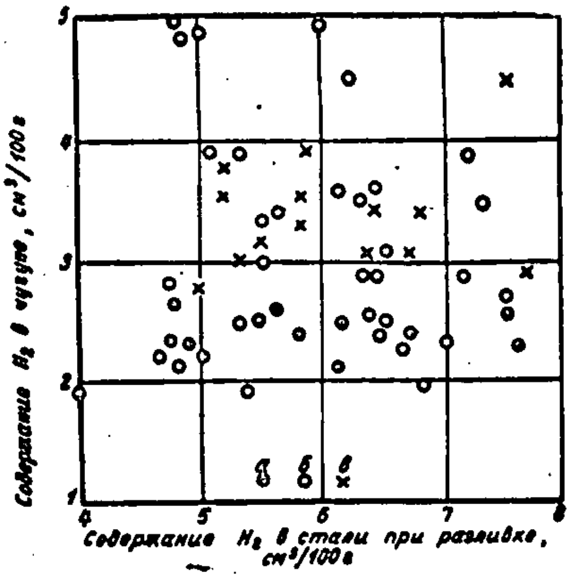

Рис. 2. Влияние содержания водорода в чугуне на содержание водорода в стали при разливке (обозначения, как на рис. 1)

Figure 1. Influence of hydrogen content in iron on hydrogen content of the metal at the melt down of an open hearth charge.
Abscissae: Hydrogen content at the melt down, $cm^3/100$ gr.
Ordinates: Hydrogen content of iron, $cm^3/100$ gr.

- a — blast having atmospheric moisture
- б — blast containing 15 gr/m^3 of water
- в — blast containing 20 $gr./m^3$ of water.

Figure 2. Influence of hydrogen in iron on hydrogen content of steel during teeming.
Abscissae: Hydrogen content of steel during teeming, $cm^3/100$ gr.
Ordinates: Hydrogen content of iron, $cm^3/100$ gr.
(designations same as in Figure 1)